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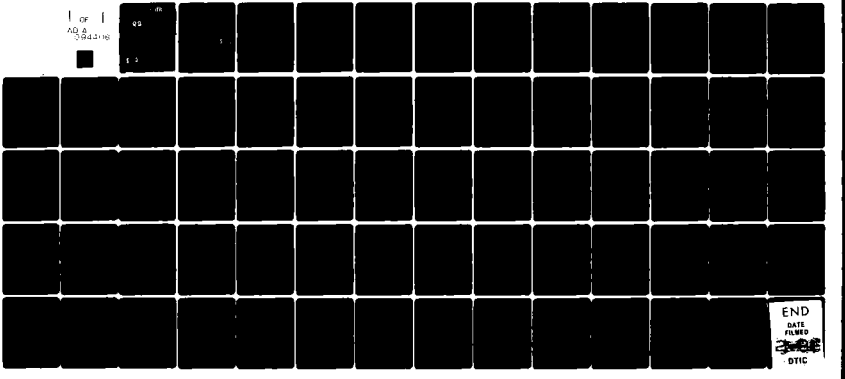

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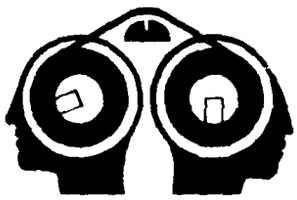

COGNITIVE SYSTEMS LABORATORY

GODDESS:
A GOAL-DIRECTED DECISION STRUCTURING SYSTEM

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UCLA-ENG-CSL-8034
June 1980

GODDESS: A GOAL-DIRECTED DECISION STRUCTURING SYSTEM

Judea Pearl, Antonio Leal, and Joseph Saleh

Technical Report

Work performed at Cognitive Systems Laboratory
School of Engineering and Applied Science
University of California, Los Angeles
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This work was supported in part by the
Engineering Psychology Programs, Office of Naval Research
Contract N00014-78-C-0372, Work Unit Number NR 197-049

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REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A094 406 / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) GODDESS: A GOAL-DIRECTED DECISION STRUCTURING SYSTEM	5. TYPE OF REPORT & PERIOD COVERED Technical Report
	6. PERFORMING ORG. REPORT NUMBER UCLA-ENG-CSL-8034
7. AUTHOR(s) Judea Pearl, Antonio Leal, and Joseph Saleh	8. CONTRACT OR GRANT NUMBER(s) N00014-78-C-0372
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of California, Los Angeles School of Engineering and Applied Science Los Angeles, California 90024	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 197-049
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research 800 N. Quincy Street Arlington, Virginia 22217	12. REPORT DATE June 1980
	13. NUMBER OF PAGES 58 pages
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Decision analysis; decision support systems; knowledge-based systems; knowledge acquisition; means-ends analysis.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a preliminary operational version of a computerized, domain-independent, decision support system which is based on a novel, goal-directed structure for representing decision problems. The structure allows the user to state relations among aspects, effects, conditions, and goals, in addition to actions and states which are the basic components of the traditional decision tree approach. The program interacts with the user in a stylized English-like dialogue, starting with the stated objectives and

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proceeding to unravel the more detailed means by which these objectives can be realized. At any point in time, the program focuses the user's attention on the issues which are most crucial to the problem at hand. The structure used is more compatible with the way people encode knowledge about problems and actions and, therefore, promises to offer the following advantages: (1) judgments and beliefs issued by the user would constitute a more valid representation of the user's experience, and (2) the user may be guided toward the discovery of action alternatives he otherwise would not have identified.

1. INTRODUCTION

Decision Support Systems (DSS) can be classified into two major categories: Knowledge-Based Systems and Situation-Based Systems. Knowledge-based systems store and employ a large data-base which contains the features and constraints specific to a given problem environment (e.g., they may employ a large medical or legal library) and enable the user to obtain an immediate access to factual information from the problem environment. It is the user's task, then, to mentally incorporate this information with additional inputs regarding the specific problem situation and come up with a decision strategy. Situation-based systems are domain-independent. They rely on the user carrying most of the background knowledge and expertise and only map into the machine that section of knowledge which the user perceives as relevant to the problem at hand. In this mode the machine acts as a sophisticated friendly 'sounding board'; it does not provide information of its own, but it assists the user in structuring and searching his own knowledge and provides advice on alternative courses of action.

Decision-Analytic technology employs situation-based support. Decision analysts who are called upon to assist in the solution of a given planning problem usually possess less specific knowledge about the problem domain than their customers. The benefit of their services stems primarily from their familiarity with a skeleton structure (i.e., a decision tree) common to all problems, and their ability to represent all problems within the confines of this structure and to draw optimal conclusions from the formal structure once it solidifies. While the optimization process is usually performed on electronic computers, the formalization phase has been accomplished manually, using lengthy interviews with persons intimately familiar with the problem domain.

In the early part of 1975 a project was initiated at UCLA to automate

the formalization phase using an interactive computer system which would guide the decision maker through a structured English-like dialogue and construct a decision tree from his responses. The objectives of this work were three-fold: (1) to provide the decision analysis industry with a practical automated tool for eliciting decision trees in cases where manual elicitation techniques are either infeasible or non-economical, (2) to cast the decision analysts' behavior into a formal framework in order to examine the principles governing the elicitation procedure and gain a deeper understanding of the dialogue process itself, and (3) to provide experimental psychologists with a standard automated research tool for comparing subjects' behaviors under various conditions and under different support techniques.

From a practical viewpoint, though, the major drawback of manual interviews is their length and cost. Since real-time analysis of decision trees is beyond the limitation of human computational capability, it invariably happens that many hours of interviews are spent on eliciting portions of the decision tree which do not have decisive bearing on the problem(s) at hand. This fact can only be discovered at a later stage once the problem structure is formalized, and a sensitivity analysis has been conducted on an electronic computer. During the interview itself, however, it is impossible for the analyst to process the entire information obtained by him up to that point, and to select the optimum course of conducting his future inquiries.

A direct man-machine interface could provide three distinct advantages. First, it offers the capability of real-time sensitivity analysis, which in turn could be used to guide the growth of the decision tree in only the more promising directions. Second, it provides an inexpensive means of updating the program with new knowledge, even by the non-technical decision maker. Finally, it opens the way to computerized real-time Delphi methods for

aggregating opinions of several remotely located experts.

This project was pursued by A. Leal and was completed in 1976 (Leal, 1976). It culminated in "An Interactive Program for Dynamic Elicitation of Decision Structures" demonstrating the feasibility of constructing a computerized system which interacts with a person in pseudo-natural English and provides assistance in structuring his problem perception, making plan recommendations and communicating the structure to others (Leal and Pearl, 1977). The program's main techniques were borrowed from both artificial intelligence (AI) and decision analysis (DA). DA provided a formal structure of knowledge representation in the form of a decision tree quantified with probability and value assessments. AI provided techniques for heuristic search of game trees and, to a lesser degree, some capabilities for natural languages processing.

Since the completion of Leal's program, the feasibility of automating the process of tree elicitation has attracted the interest of several other laboratories. Merkhofer, Miller, Robinson, and Korsan (1977) at SRI describe a tree structuring support system for command and control applications. Leal, Levin, Johnston, Agmon, and Weltman (1978) at Perceptronics describe an interactive computer aiding system for group decision making designed to support crisis management situations.

GODDESS, the structuring-aid system reported in this paper, represents a methodological extension of the works above in breaking away from the confines of decision tree representations and employing a richer structure which, we believe, is more compatible with the way people perceive their problems. The paper is organized as follows. Section 2 presents the deficiencies of decision tree representations which prompted us to adapt the goal-directed structure outlined in Section 3. Section 4 describes the network of relationships constructed by GODDESS and how judgments about these relationships propagate

through the network. Section 5 outlines the philosophy and procedures used by GODDESS to control the user's focus of attention. Section 6 presents a sample dialogue between GODDESS and a user seeking financial advice. Conclusions and prospects for future developments are discussed in Section 7.

2. DEFICIENCIES OF DECISION TREE REPRESENTATION

Experience with the operation of Leal's program confirmed earlier hopes that due to the structural simplicity of decision trees, only very primitive levels of language-understanding would be sufficient to conduct natural, English-like dialogues. However, the lack of sophisticated language understanding features, aside from accounting for the simplicity of the program, also resulted in several deficiencies. The most serious deficiency arises from the constraint of representing knowledge in tree form.

In many real-world applications, the decision maker may not perceive a problem in the form of a time sequence of decision alternatives and event outcomes, but rather as a static network of influences surrounding issues and factors. Consider, for example, our perception of the environmental pollution problem. The issues of capital investment, energy needs, energy supply, unemployment, public health, etc., all seem to be tightly interwoven in a network of cause and effect relationships. The first step in attacking such a problem should be to explicate the underlying causal network rather than to hypothesize and evaluate various action/event scenarios.

When a person confronts such a complex problem he is rarely aware of the set of relevant alternative actions available to him at the onset. In fact, he usually hopes the analyst would help him identify those alternatives on the basis of certain things he desires to achieve and others he wishes to prevent.

Imagine how awkward it must sound for a person planning the long-range economic policy of the U.S. to be asked:

Computer: "What seems to be your problem?"

Planner: "Our long-range economic policy."

Computer: "List the alternatives available to you."

A much more natural and useful question would be:

Computer: "List the effects you would like to see accomplished." Or,

Computer: "List your concerns regarding the present situation."

The user may become aware of his immediate options only after unraveling the processes which influence the desired and undesired effects, the preparations needed to make these processes more or less effective, and the conditions which should prevail before an action becomes applicable.

The major difference in the formal representation required for such problems and the one handled by decision trees is that the atomic entities admitted by the latter representation are restricted to be descriptions of 'world states' or decision 'situations'. The decision maker can express relations among these situations but is unable to express relations between their constituents. For example, when a decision maker is asked to assess the value of a situation resulting from a given event/action sequence, he is presented with the entire sequence and is forced to aggregate the effects of all the event/action components by mental manipulations. He cannot, for example, explicitly express the belief that raising taxes is a positive contributor to unemployment regardless of other situational factors such as air pollution or the energy embargo. Likewise, he is unable to state explicitly that increased employment (a situational factor) may enhance tax payers' willingness to support more public transportation systems. Instead, he would be required to globally assess the likelihood of obtaining tax payers' support given prior actions and situations.

Decision Analysis is founded on the paradigm that the reliability of human judgments increases when the format of these judgments are made more compatible with the internal format used by people to encode experience. In fact, the sole rationale of problem-decomposition 'divide and conquer' approaches

is to reformulate a given problem statement in terms of many, so-called more 'elementary', problem statements to which reliable judgments can be assigned. The reason that one expects these elementary judgments to be more reliable than those involving global considerations is only that the former are more likely to match the format in which human experience is encoded. The decomposition affected by decision tree analyses only offers the first step toward a structural match between the external and the internal codes. The fragmentation, however, remains too crude to allow the user to express beliefs in a natural and, therefore, more reliable manner.

The main objective of the current research project has been to devise a richer structure for eliciting knowledge about decision problems, a structure in which aspects, issues, and conditions are represented as independent entities. On the basis of such a structure, it becomes feasible to construct a decision support program that, starting with the stated objectives, guides the decision maker toward the discovery of action alternatives he otherwise would not have identified.

3. A GOAL-DIRECTED APPROACH

To facilitate an 'issue-oriented' problem elicitation program, the internal machine representation of problem situations could be based on the methodology known in artificial intelligence as 'problem reduction' or 'means-ends analysis' (Nilsson, 1971). Each node in this structure represents a subproblem or a subgoal rather than a state description. The task of describing a problem as a collection of interdependent issues (i.e., hopes and concerns) is regarded as a reduction of the global problem into several components. These can be further reduced to their constituencies, and so on.

A 'means-ends analysis' was first employed in the General-Problem-Solver (GPS) program developed in the late 1960s (Ernst and Newell, 1969). The program is controlled by 'differences': a set of features which make the goal different from the current state. The programmer had to specify along what dimensions these differences are measured, which differences are easier to remove, what are the operators available for the reduction of the differences, and under what condition each reduction operator is applicable. A successful planning program, called STRIPS, based on the same principles was implemented at SRI to plan the actions of an object-manipulating robot (Fikes and Nilsson, 1971) In STRIPS too, actions are brought up for consideration by virtue of their potential for reducing the differences (mismatched logical assertions) standing between the desired goal and the current state. When the current state does not possess the conditions necessary for enacting a desired difference-reducing operation, a subgoal is created to generate the missing conditions. The structure underlying this form of reasoning is no longer a tree but an AND/OR graph. The OR nodes represent various types of actions one can employ in attempting to achieve a given subgoal, and the AND nodes represent the remaining subgoals (differences) all of which should be resolved before a solution is reached. These latter

sets of subproblems are of two types: the first contains a set of preconditions that must be realized before the enactment of a previously identified desirable action could be feasible, the second contains a set of adverse effects (additional differences) introduced by such an action.

A similar AND/OR graph structure has been selected as the basic representation for our decision-structuring program and, since at each level of expansion the content of deeper levels is determined by the available set of subgoals, we call it a goal-directed program (Pearl, 1978) with the acronym GODDESS.

To demonstrate the difference between this structure and the traditional decision tree, consider two possible conceptualizations of the problem of handling a terrorist attack. Figure 1 represents a possible beginning of a decision tree describing the crisis, while Figure 2 represents a goal-directed structure for the same problem. The two basic entities in the latter structure are actions (in ⌂ boxes) and subgoals or issues (in ▭ boxes). The root of the graph labeled TERRORIST ATTACK is recognized as involving two main issues: securing the hostages' safety and discouraging future attacks. These are connected by an AND arc to indicate that both issues must be dealt with simultaneously. At this point the natural question for the computer to ask would be, "Could you think of an action which would serve the hostages' safety and at the same time would deter future attacks?". The possibility of 'ATTACK TO RESCUE' immediately comes to one's mind, and the various aspects of this suggestion are explicated. Other actions, intended to resolve each subgoal separately, are then elicited. Each action is characterized by two lists: (1) a preconditions list and, (2) an effects list. Any one of the preconditions which is not yet satisfied generates a subgoal (e.g., the condition 'terrorists must agree to postpone deadline' generated the subgoal 'provide terrorists with incentive for postponement').

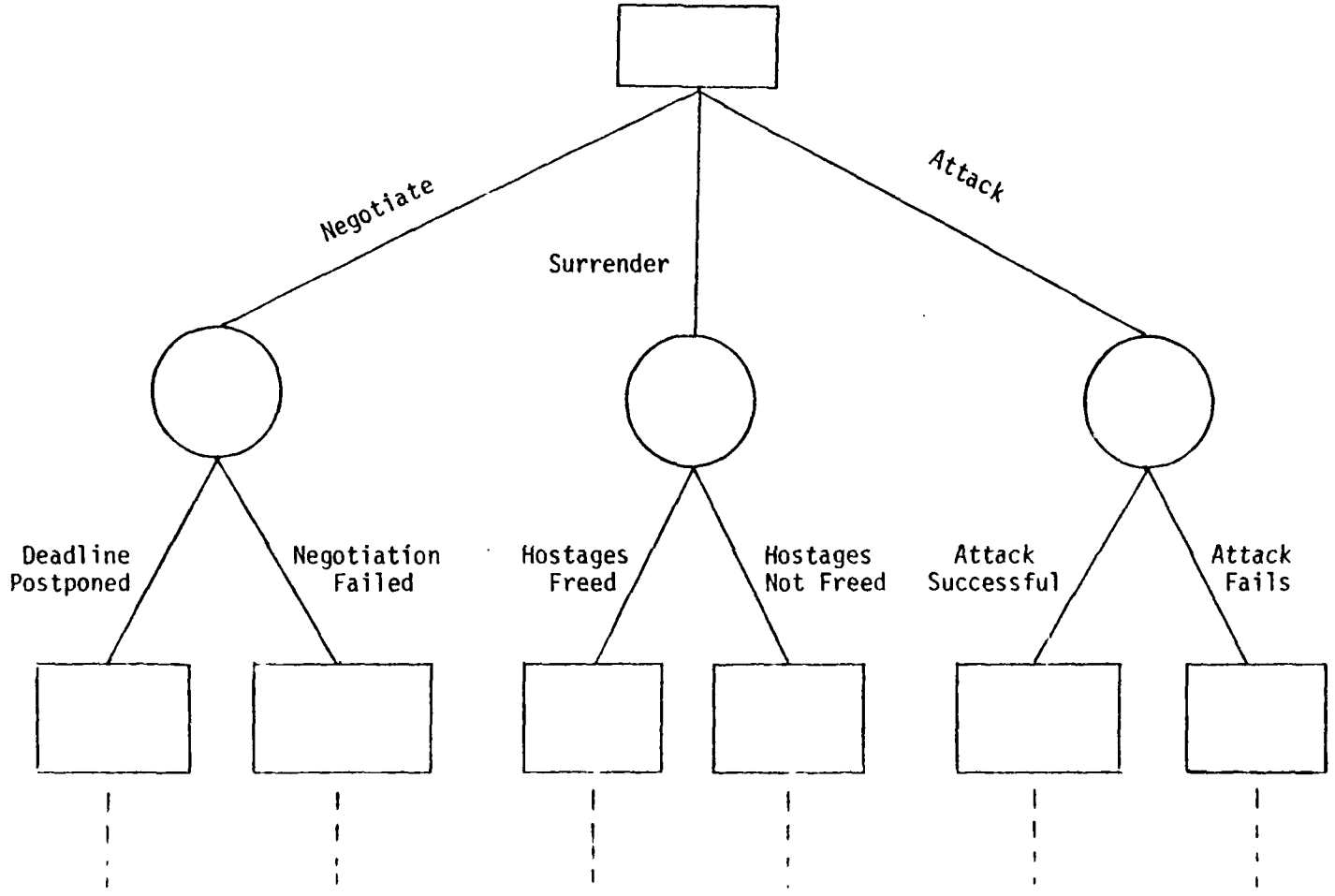


Figure 1. Decision Tree Representation of Terrorist Attack Problem.

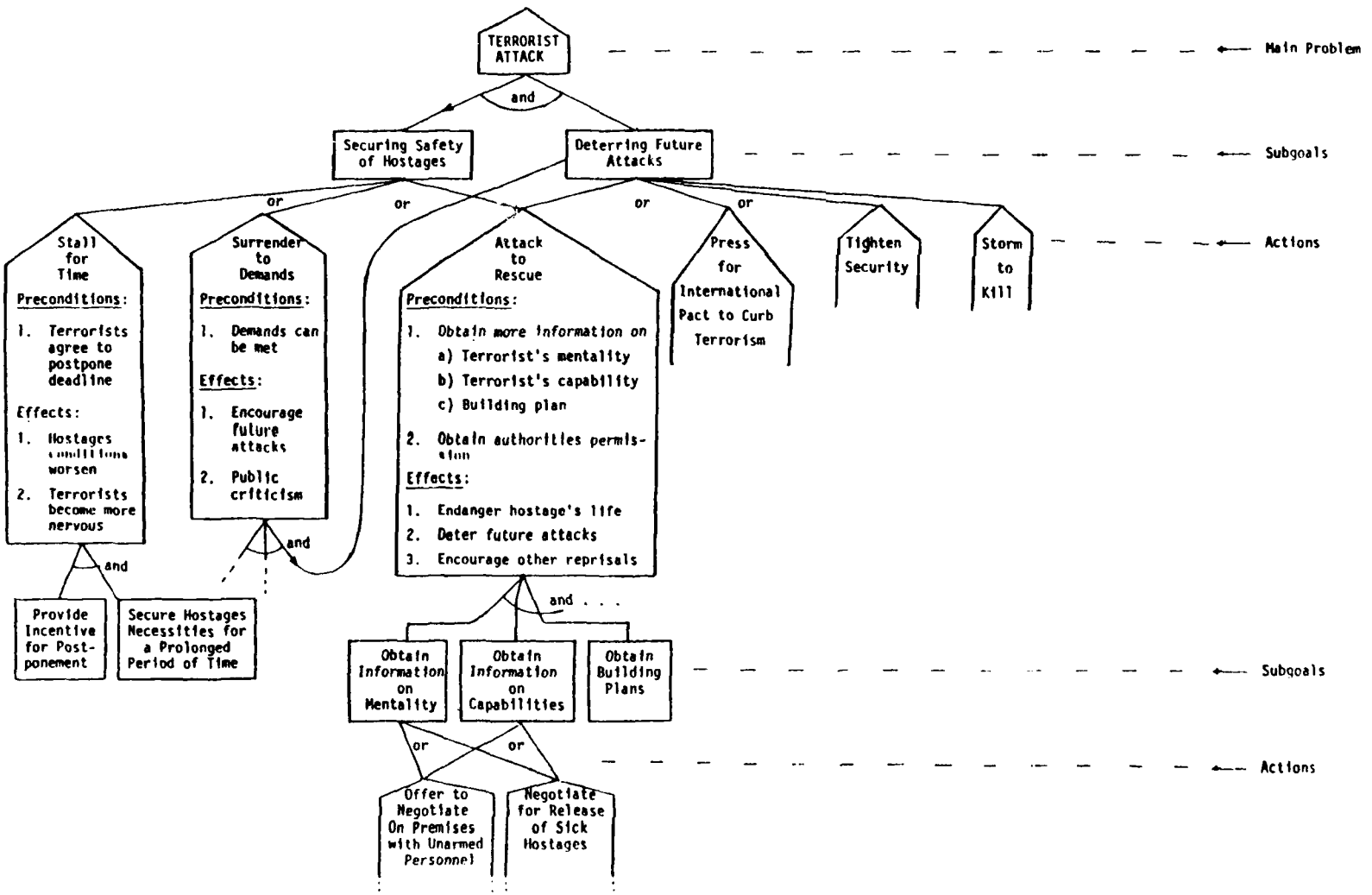


Figure 2. Goal-Directed Representation of Terrorist Attack Problem.

Some arcs of the graph may point back toward higher levels in the structure (e.g., one of the effects of 'surrender to demands' is found to be 'encourage future attacks' which generates, since it is an adverse effect, a subgoal of eliminating this effect, namely the subgoal 'deterring future attacks' which is already listed in the first level).

The main advantage of this structure is that the intent of each action is spelled out explicitly prior to naming the action. The analysis proceeds from the ends toward the means which encourages the user to discover novel alternatives. For example, the alternative 'negotiate for release of sick hostages' only came to mind after drawing the subgoals 'obtain information on terrorist's mentality and capabilities'. Clearly, similar goals may also implicitly influence one's thoughts during a decision tree elicitation. For example, the alternative 'negotiate' in Figure 1 may have been identified for the purpose of obtaining additional information about the terrorist mentality. However, not having such purposes spelled out formally may cause the user to neglect exploring a large set of alternatives which can make up a workable solution plan.

In formal problem-solving, such as theorem proving or robot planning, problems are said to be solved when a sequence of operators is found which removes all differences between the desired and the current state. In real-life problems, such as the terrorist problem above, issues seldom get 'resolved'. They are, at best, alleviated or controlled within acceptable ranges. For example, one has no guarantee that meeting the terrorists' demands would result in the hostages' safety. The latter is only a plausible expectation. Similarly, one cannot be sure of the degree to which storming the building would deter future terrorist attacks. Such estimates must be assessed using educated guesses and quantified using a formal structure. GODDESS is equipped with procedures for handling partial-satisfaction as well as uncertain and value-driven

relationships. The descriptions of the actions also contain information on the degree to which each of the preconditions contributes to the realization of each subgoal. For example, the action 'attack to rescue' would qualitatively specify how critical it is to obtain the desired information in order to secure the hostages' safety during the attack. Similarly, a value judgment must be attached to each of the mentioned subgoals in order to determine both the relative merit of candidate solution plans and the direction of future elicitation queries.

It is interesting to note that the structure depicted in Figure 2 could also constitute a '<u>frame</u>' (or template) for representing the generic aspects of terrorist-attack problems. Once elicited in detail, such a structure could be pre-stored as an 'expert' on terrorist confrontations and be consulted when a particular crisis develops. The advantage of pre-storing the 'frame' is that during the crisis, only the problem-specific parameters need be explored in detail. On the basis of these parameters, the program could also suggest pre-stored contingency plans for consideration by the user, provide explanation for its suggestions, and, to some degree, be able to understand queries posed to it in English.

4. ORGANIZATIONAL DESIGN AND VALUE PROPAGATION

Figure 3 shows the skeleton of the graph used by GODDESS. Its main components are the following:

(1) Goal - the major objective of the decision maker.

(2) Subgoals - the goal 'dimensions', 'attributes', or detailed items that combine to form the overall goal.

(3) Actions - the major action strategies that are open to the decision maker for advancing a particular subgoal.

(4) Modes - the possible implementation methods of performing each action.

(5) Preconditions - those states of nature or the environment that are desired for permitting a particular (action) mode to be implemented effectively.

Figure 3 should be thought of as a decision network. Thus, the goal is divided into many subgoals, each subgoal has a number of possible actions that could accomplish it, each action has a number of ways (modes) it can be performed, and each mode has a number of preconditions that must be completed. Once the preconditions are specified, they lead directly to new subgoals, that is, the subgoal of completing the specific precondition that allows actions to be taken, etc. If the realization of a precondition is beyond the direct control of the user and is, instead, perceived to depend on externally controlled eventualities, that precondition is then treated as an uncertain event node quantified by likelihood estimates. This structure can then be repeated recursively.

Cross-relationships can also exist in the graph. For example, it is possible for one action to have a beneficial or adverse effect on a subgoal to which it is not directly connected. These cross-relationships are called 'side effects' and must be identified and characterized by the user so that the program

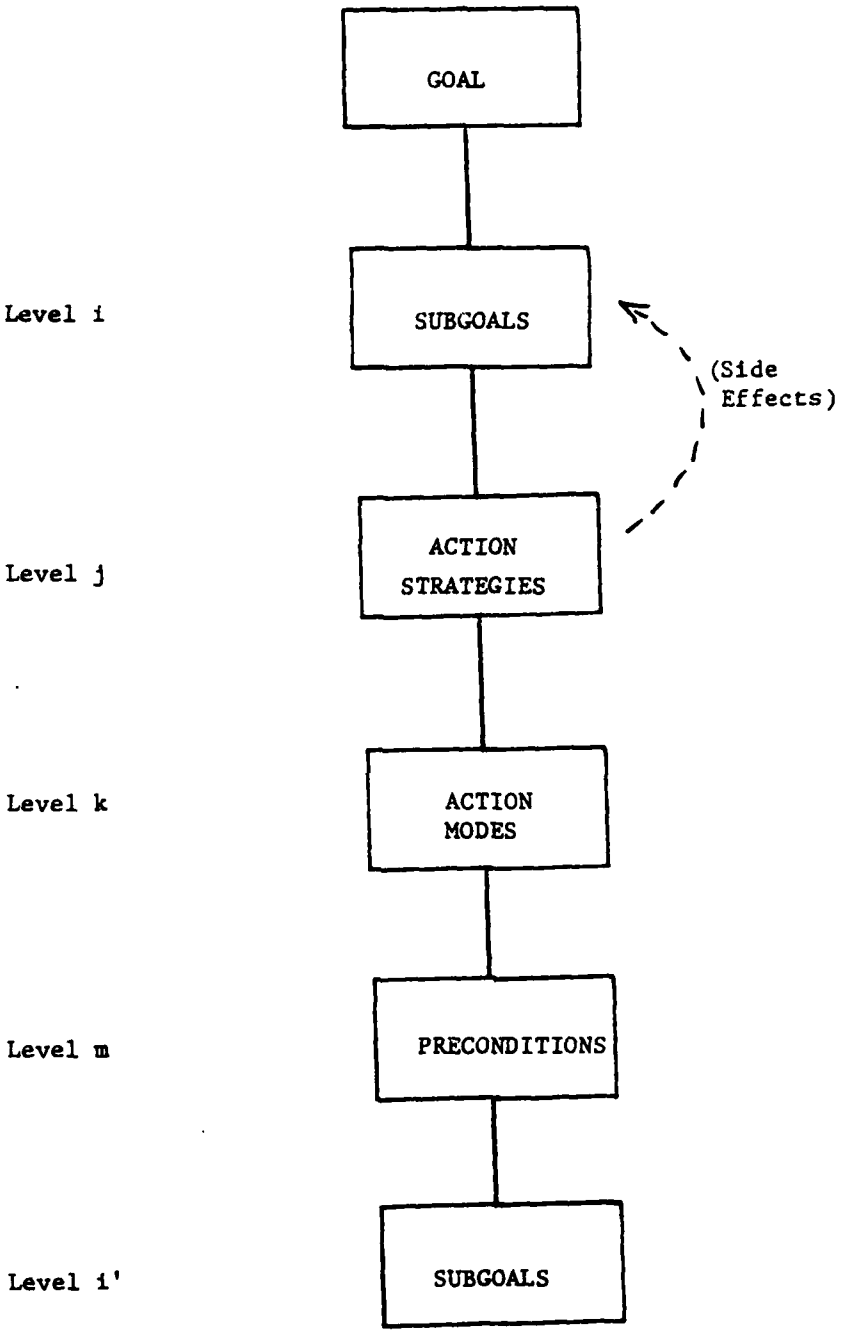


Figure 3. Model Structure

accounts for the full impact of each action.

The following sections outline each of the above components in detail including the required information values and algorithms for aggregating them. The structure 'levels' have been indexed for purposes of referencing the various values and parameters.

The Major Goal

The user will usually state the major goal in terms of a particular state of affairs that he desires. The overall goal has an associated numerical value G ($0 \leq G \leq 1$) that captures the user's perception of satisfaction with different levels of accomplishment. It is the objective of the decision support system to maximize this value. The value of G need not be 0 at the beginning of the elicitation session. That is, a portion of the goal may already be attained. The value G = 0 will reflect a pessimistic state of affairs and G = 1 an optimistic situation, conveniently chosen by the user for reference purposes.

Subgoals

With the major goal stated, it is then necessary to explore in detail the goal dimensions, or 'subgoals'. The subgoals are those aspects of the world which the user perceives as integral components of the major goal. The subgoals may reflect either desired dimensions or adverse dimensions (hopes and concerns). Adverse dimensions are those whose elimination supports goal attainment. GODDESS forces the user to express all issues, hopes as well as concerns, as areas for potential improvement, i.e., subgoals. For example, the fear of losing one's job will be expressed as a subgoal 'maintain job' or 'reduce likelihood of losing job'. The subgoals should completely describe the major goal in the sense that if all desired conditions were fulfilled to their utmost extent and all undesirable conditions eliminated, the goal would be perceived as fully satisfied.

The relation between the major goal and the subgoals is characterized by two numbers associated with each subgoal: value and weight. The value V_i ($0 \leq V_i \leq 1$) of subgoal i is the degree to which it has been achieved. (This parallels the value G for the goal.) The weight W_i ($0 \leq W_i \leq 1$) for subgoal i is a measure of its importance relative to the other subgoals. The user is instructed to estimate the degree to which progress toward each individual subgoal contributes to the satisfaction of the major goal. The weights are constrained to sum to 1 ($\sum_i W_i = 1$).

The goal value G is obtained from the subgoal values and weights by a linear combination ($G = \sum_i W_i V_i$). Thus, the subgoal structure corresponds to a linear multi-attribute model.

Action

After the list of specific subgoals has been established, the decision support system begins elicitation of actions. For each subgoal, the user is asked to think of possible actions that would help produce improvements in each of the subgoals mentioned. More than one action may be listed. However, each action should have the capacity, by itself, to affect the subgoal, and they should be mutually exclusive.

Actions are divided into two levels: action 'strategies' and action 'modes'. An action strategy is a statement of a plan or a short description of what is to be done. Each action strategy is characterized by an 'effectiveness' quantifier E_j ($0 \leq E_j \leq 1$), which measures the level of subgoal attainment to be expected if action strategy j were executed.

Each action strategy can be supported by a set of mutually exclusive action modes. An action mode is a more detailed specification of how the action strategy is to be implemented. For example, the mode may specify the time, place, technique, and various resources to be used in support of the parent

strategy. The action mode effectiveness E_k ($0 \leq E_k \leq 1$) is the amount that the corresponding mode affects the success of the parent action strategy. The benefit of characterizing actions by a two-level structure lies in the fact that many properties of an action strategy (e.g., preconditions) would be identical to all its modes. This would enable us to store these common sets of properties in the description of the parent strategy, thus saving the storage and elicitation time otherwise consumed by duplication.

Preconditions

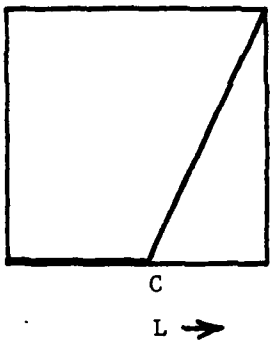
A 'precondition' is a state of the environment that must exist before an action mode (or strategy) can be implemented effectively. Precondition satisfaction need not be an 'all or nothing' requirement. The effectiveness E_k of an action mode may vary smoothly with completion of the precondition state. Therefore, GODDESS instructs the user to characterize each precondition by two parameters: a measure of completion L_m ($0 \leq L_m \leq 1$), and a criticality threshold C_m ($0 \leq C_m \leq 1$). The criticality is a threshold on the completion level of the precondition below which the effectiveness of the corresponding action mode is nullified. A threshold of 0 means that the action mode can be executed (to some degree of effectiveness) even if the precondition exists at its minimum level of attainment. A threshold of 1 means that the mode cannot be implemented (or has 0 effectiveness) unless the precondition is fully satisfied.

The relationship between the precondition completion level L, its criticality C, and the effectiveness of the supported mode is captured by a truncated linear function δ (Figure 4):

$$\delta(L, C) = \begin{cases} \frac{L-C}{1-C} & \text{if } L \geq C \\ 0 & \text{if } L < C \end{cases}$$

Since all of the preconditions should be completed before the effectiveness of

$E=\delta(L,C)$



$$\delta = \begin{cases} 0 & \text{if } L<C \\ \frac{L-C}{1-C} & \text{if } L \geq C \end{cases}$$

L = Precondition Completion Level

C = Criticality Threshold

Figure 4. Criticality Function

the action mode can be fully realized, the overall effectiveness of the action mode can be obtained by taking the product of the criticality functions of each of the connecting preconditions: $E = \prod_i \delta(L_i, C_i)$.

There are two types of preconditions: controllable and uncontrollable. A 'controllable' precondition means that the level of its completion is either known or can be controlled directly. An 'uncontrollable' precondition is one whose current level of attainment is both uncertain and not directly adjustable. For example, in the context of business decision making, the user may consider the action mode 'lower prices by 10 percent' as a potential action for achieving the subgoal 'capture a larger share of the market'. The effectiveness of this action depends (among other factors) on the variables 'competitor's prices' and 'buyers' price awareness'. The latter may be controlled via advertisement while the former must be treated as an uncertain variable not subject to one's direct control or scrutiny. A more detailed description of structuring uncertain events is given in the next section.

Whenever GODDESS realizes (using a sensitivity analysis described in section 5) that the success or failure of the overall plan hinges critically on a given precondition, it proclaims the fulfillment of this precondition as a new subgoal. This proclamation calls the user's attention to a new spectrum of problems aimed toward satisfying the corresponding precondition, thus repeating the entire structure including action strategies, action modes, further preconditions, etc.

Uncertain Events

Uncontrollable preconditions require a special treatment different from the one above, since the proclamation of subgoals directed toward satisfying uncontrollable preconditions may only introduce unpursuable objectives into the structure. Although the level of completion of an uncontrollable precondition

cannot be directly adjusted by a user's actions, the user may be able to implement actions to enhance the likelihood of some events which, in turn, would increase the expectation of reaching a higher level of completion for the desired precondition. In such a case, rather than pursuing subgoals that directly satisfy the precondition, a more useful approach would be to establish subgoals which are directed toward increasing the probability of the favorable events and decreasing the probability of unfavorable events. For instance, lowering one's bid is normally conceived as an action enhancing one's chances of winning a contract and not as an action aimed at increasing the completion level of contract winning.

GODDESS associates two parameter-vectors with each uncontrollable precondition. The first vector $[p(t_1), p(t_2), \ldots]$ contains the probability of occurrence of each uncertain outcome. The second vector $[(L|t_1), (L|t_2), \ldots]$ contains the level of completion of the precondition, given the occurrence of the corresponding uncertain outcome. Once these vectors are elicited, the system examines the elements of the second vector and proclaims a new subgoal aimed at increasing the probability of the most desirable outcome, i.e, the one with the highest $(L|t)$. Usually, a strategy aimed at increasing the likelihood of the desired outcome is also helpful in avoiding its undesirable counterparts. Therefore, it is not necessary to set up a separate subgoal for each outcome.

As the expansion of the new subgoal continues, the probability vector is updated. Using the two vectors above, the expected level of attainment of the major goal can be calculated by:

$$G = \sum_i (G|t_i)\, P(t_i)$$

where $(G|t_i)$ is the value of the major goal computed by assuming that outcome

t_i has occurred, and that the best action was accordingly selected. However, as the number of uncontrollable preconditions across the graph increases, the number of required calculations proliferates rapidly, since each possible combination of uncertain outcomes must be considered separately.

To overcome this complexity problem, a heuristic rule has been employed. The rule computes the expectation of G by fixing the impacts (i.e., the criticality functions $\delta(L_i, C_i)$) of all uncontrollable preconditions in the graph except the one examined for action selection, at their local expected value.

Side Effects of Actions on Subgoals

It oftens happens that the execution of a particular action has a beneficial or adverse effect on a subgoal to which it is not directly connected. GODDESS alerts the user to this possibility by asking whether any such effects are present and, if the answer is positive, it elicits an impact measure, I, for the relationship. The impact I_i^k $(0 \leq I_i^k \leq 1)$ is considered to be the relative amount that the action k, if implemented, will increase or decrease the level of attainment of the affected subgoal. Assume that the subgoal attainment level has already reached a value V_i as a result of some action directly connected to it. If the remote action has a beneficial effect of strength I_i^k, V_i will increase to $V_i' = V_i + (1 - V_i)\, I_i^k$. If the remote action has an adverse effect on the subgoal, it will lower the subgoal attainment level V_i to $V_i' = V_i - V_i I_i^k$.

When several actions affect the same subgoal remotely, their cumulative impact is computed by applying the revision formulas for each individual action in succession (in the order of elicitation).

5. DIALOGUE MANAGEMENT

One of the main advantages that computerized decision-support systems offer over manual methods is the ability to identify (in real-time) which areas of the problem graph deserve further exploration and to guide the dialogue in such a way that at any stage the user would focus attention on the most crucial issues. The procedure for selecting the crucial issues is called 'dialogue management'.

The information provided by the user is constantly mapped into a formal structure which permits GODDESS, at least in principle, to halt the dialogue at any convenient time and generate a provisional recommendation. This can be done simply by calculating the value of the goal, G, for each feasible action plan and selecting that plan which results in the highest expected value of G given provisional likelihood assessments for the various conditions involved. At an early stage of the dialogue such a plan is likely to be grossly suboptimal as the selection is based on provisional and unreliable assessment of abstract quantities such as attainment levels, strength of impact, criticality, etc. The motivation for continuing the dialogue lies entirely with the belief that the reliability of the user's judgments improves as deeper levels of the tree are explored and the issues considered become more detailed and concrete. The expected improvement in reliability would, in turn, result in a more valid computation of G and the selection of a higher quality plan. This expected improvement in plan quality, which constitutes the driving force behind the necessity to ask the user for more detailed information, was also chosen as a criterion for determining the future direction of the dialogue. The formal definition of the above criterion is given in the following paragraphs.

Let x be the value of some parameter whose assessment was requested by GODDESS, e.g., level of completion of a given precondition. Let $G(x_1, x_2)$

denote the level of attainment of the major goal when actions were selected assuming that $x = x_1$ while, in reality, $x = x_2$ is the true value of the parameter in question. Thus, if the actual value of the parameter is an unknown random variable x and the user provides GODDESS the estimate $\check{x}$, then the expected increase in plan quality due to resolving the uncertainty in x is given by:

$$E_x(\Delta G) = E_x[G(x, x) - G(\check{x}, x)]$$

GODDESS may use this expected value as a criterion for identifying the direction with the highest need of further exploration; the subgoal with the highest level of $E_x(\Delta G)$ with respect to its completion level x would be brought up for the user's attention.

In order to compute $E_x(\Delta G)$ the user should provide the program two assessments: a provisional estimate $\hat{x}$ of the level of completion that the subgoal would eventually attain (in a well-planned strategy) and an estimate of his/her uncertainty regarding the true value of x. The simplest way of eliciting the latter is for the user to specify a range $[x_{max}, x_{min}]$ where x is likely to be found. The estimates $\hat{x}$, x_{max}, and x_{min} could then be used to fit a reasonable (usually rectangular or triangular) probability distribution function for x to be used for calculating $E_x(\Delta G)$. Detailed calculations of $E_x(\Delta G)$ are given by Saleh (1980).

Our experience in utilizing $E_x(\Delta G)$ as a criterion for node selection has revealed a practical difficulty stemming from a basic flaw in the method of its estimation. After one or two levels of expansion, the $E_x(\Delta G)$ of all terminal nodes became identically equal to zero. Since the impacts of subgoals are quantified by numbers smaller than one at each junction, the value of G becomes less sensitive to variations in the levels of subgoals remote from the root. A

parameter would be assigned non-zero $E_x(\Delta G)$ only if the actions selected on the basis of x are different than those selected on the basis of $\hat{x}$. However, as the subgoal appears in deeper levels of the graph, the deviation in its completion level necessary to prompt a change in action plan becomes substantially greater than 1. Eventually none of the terminal nodes will be capable of inducing a change in plan by its own variation and so all terminal nodes will be assigned a zero $E_x(\Delta G)$ value.

Although in some rare cases the utility of analysis for all terminal subgoals would indeed be zero, and should be interpreted as a signal to stop further analysis, in the more common case, this phenomenon is an artifact of the approximations used to calculate $E_x(\Delta G)$. The formula for the $E_x(\Delta G)$ measure has been derived under the assumption that the values of all other quantifiers in the graph except the one in question remain fixed at their most likely value. However, since the value of other subgoals are also subject to uncertainty within their range of variability, these too should also be treated as random variables. Consequently, the correct expression of the expected value-of-analysis of variable x_i should be:

$$E(\Delta G)_i = E_{\underline{x}} [G_{\underline{x}}(x_i, x_i) - G_{\underline{x}}(\hat{x}_i, x_i)]$$

where $\underline{x}$ stands for the totality of all variables which affect the computation of G.

The computation of $E(\Delta G)_i$ by the formula above would require an enormous amount of data for estimating the joint distribution of $\underline{x}$ as well as a great amount of time to process that distribution. Consequently, we decided to drive the dialogue by an approximate criterion related to the likelihood of inducing a change in action plan rather than the exact value of $E(\Delta G)_i$. The criterion chosen is α_i times R_i/Δ_i, the ratio between the range of variation of variable

x_i and the amount of variation in x_i required for inducing a change in action plan. The multiplier α_i measures the sensitivity of G to variations in x_i if a change in plan is induced and should, therefore, multiply R_i/Δ_i to yield a criterion approximating $E(\Delta G)_i$. Δ_i and α_i are calculated by assuming that the levels of all subgoals, except the i^{th}, are fixed at their provisional values.

Even with this simplification the calculation of Δ_i is not a simple matter. To decide whether a given variation in x_i warrants a change in action plan requires a manipulation of the entire graph since each action may influence the goal via several paths and the side-effects are combined multiplicatively.

The computation was facilitated by recognizing that under the propagation rules defined in Section 4 the function $G(x_1, x_2)$ would be a piecewise linear function of both arguments, completely specified by a list (vector) of three parameters, a, b, and c, which determine the level, break point, and slope of the function, respectively. The parameters (a, b, c) could be calculated recursively, top down, and be stored as a characteristic vector for each node of the graph. Using these vectors, the determination of Δ_i and α_i can be accomplished by local computation. A detailed description of this technique, including the propagation rules for the (a, b, c) vectors, is given by Saleh (1980).

In order to maintain a reasonable continuity of attention we have chosen to treat the entire subgraph residing between a given subgoal and its descendent subgoals as a single atomic unit for dialogue management purposes. Thus, once a subgoal is selected for expansion, the entire subgraph supporting it (i.e., actions/modes/subgoals) becomes committed for analysis in a breadth-first fashion.

6. SAMPLE PROTOCOL

This section contains an unabridged sample protocol, resulting from a dialogue between GODDESS and a user. In this stage of the implementation, elicitation management was not active and nodes were expanded in breadth-first order (left-to-right). Evaluation of the major goal was accomplished by considering all possible combinations of actions--a process which did not take a great deal of computer time with a small decision structure. Uncertain events were assumed to be binary.

Background

The user is a man in his mid-thirties with a Ph.D. in an engineering field of high demand. He is currently employed in a high technology research and development company. The company's incentive and payroll system is organized such that the total pay and qualification for more overtime are directly related to the quality of work. The user owns a house in the city and a piece of undeveloped land in the suburban area. He has never owned or managed his own business before. However, he believes that with the proper assistance he will be capable of conducting a personally owned business. He is married with two children both of preschool age. At the present time, his expenses are covered by his present salary, but he is unable to save substantial amounts of money. He considers his problem to be that of planning a strategy for improving his financial status without reducing the standard of living of his family.

The user responses are preceded by an asterisk (*). User comments, referenced by the numbers in the right margins, are shown in the Appendix. The symbol '?' means that the user has not fully understood GODDESS' instruction which prompts GODDESS to rephrase its request or provide explanatory comments.

Dialogue

```
      start
  Goal-Directed Decision Support System
  Do you wish to begin a new problem?
* yes
  What is your problem?
* Improve my financial status
  We will assume that your ultimate goal is to
  reach a satisfactory solution of the problem:
  "Improve my financial status"
  List all major objectives which, if realized, would
  contribute to the fulfillment of the goal.
  1:
* ?
  Let's analyze ways of achieving the main goal by
  considering its major components.  List the
  major objectives which must be achieved before the goal can be attained.
  1:
* Have large assets
  2:
* Have high steady income
  3:
*
  Estimate the importance (0 to 10) of the objectives above.
  objective 1:  "Have large assets"
* ?                                                              C-1
  Assume that all objectives are partially satisfied
  and that you have a choice of increasing the
  level by which a particular objective will be attained.
  Rate the importance of such an improvement
  on each of the listed objectives.  Use a scale of 0 to 10
  for assessing the degree of importance:
  the higher the assessment value, the more important the objective.
  objective 1:  "Have large assets"
* 6
  objective 2:  "Have high steady income"
* 4                                                              C-2
  What level (0 to 10) is the following objective
  expected to reach in a well-planned strategy?
  objective 1:  "Have large assets"
* ?
  Recall your previous experiences in this problem area.
  Imagine similar situations in the past and
  assume that you are given a sufficient amount of
  time to plan your actions judiciously.
  Estimate a reasonable level (0 to 10) of attainment
  for each objective which reflects
  both environmental constraints and your available resources.
  objective 1:  "Have large assets"
* 6                                                              C-3
  objective 2:  "Have high steady income"
* 7                                                              C-4
```

```
  Let's consider the objective "Have large assets"
  List all possible action strategies that you can take
  toward the fulfillment of "Have large assets".
  Make sure that the list contains all
  physically feasible approaches (including possibly
  "doing nothing") and that no two of them can be combined.
  1:
* Develop my land
  2:
* Invest in stock market
  3:
* Invest in real estate
  4:
* Speculate in precious metals
  5:
*
  Suppose that these actions are taken.  What is your
  assessment of the resulting level of attainment
  of "Have large assets" under such conditions?
  action strategy 1:  "Develop my land"
* 9                                                        C-5
  action strategy 2:  "Invest in stock market"
* 6                                                        C-6
  action strategy 3:  "Invest in real estate"
* 7                                                        C-7
  action strategy 4:  "Speculate in precious metals"
* 6                                                        C-8
  Consider the following objectives"
   1  Have large assets
   2  Have high steady income
  Does the action strategy "Develop my land"
  have any adverse effect on any of the above objectives?
* yes
  List the affected objectives by number (separated by spaces)
* 2                                                        C-9
  Suppose that the objective "Have high steady income"
  would otherwise attain a level of (for example) 8.
  What would its new level be assuming that
  "Develop my land" was enacted?
* 5
  Consider the following objectives:
   1  Have large assets
   2  Have high steady income
  Does the action strategy "Invest in stock market"
  have any adverse effect on any of the above objectives?
* no                                                       C-10
  Consider the following objectives:
   1  Have large assets
   2  Have high steady income
  Does the action strategy "Invest in real estate"
  have any adverse effect on any of the above objectives?
* no                                                       C-11
  Consider the following objectives:
   1  Have large assets
   2  Have high steady income
```

```
  Does the action strategy "Speculate in precious metals"
  have any adverse effect on any of the above objectives?
* yes                                                          C-12
  List the affected objectives by number (separated by spaces)
* 2
  Suppose that the objective "Have high steady income"
  would otherwise attain a level of (for example) 8.
  What would its new level be assuming that
  "Speculate in precious metals" was enacted?
* 6
  Let's consider the objective "Have high steady income"
  List all possible action strategies that you can take
  toward the fulfillment of "Have high steady income".
  Make sure that the list contains all
  physically feasible approaches (including possibly
  'doing nothing") and that no two of them can be combined.
  1:
* Open a business
  2:
* Find a second job
  3:
* Increase my over-time
  4:
*
  Suppose that these actions are taken.  What is your
  assessment of the resulting level of attainment
  of "Have high steady income" under such conditions?
  action strategy 1:  "Open a business"
* 8                                                            C-13
  action strategy 2:  "Find a second job"
* 4                                                            C-14
  action strategy 3:  "Increase my over-time"
* 4                                                            C-15
  Consider the following objectives:
   1  Have large assets
   2  Have high steady income
  Does the action strategy "Open a business"
  have any adverse effect on any of the above objectives?
* yes
  List the affected objectives by number (separated by spaces)
* 1                                                            C-16
  Suppose that the objective "Have large assets"
  would otherwise attain a level of (for example) 8.
  What would its new level be assuming that
  "Open a business" was enacted?
* 3
  Consider the following objectives:
   1  Have large assets
   2  Have high steady income
  Does the action strategy "Find a second job"
  have any adverse effect on any of the above objectives?
* yes                                                          C-17
  List the affected objectives by number (separated by spaces)
* 1
```

```
  Suppose that the objective "Have large assets"
  would otherwise attain a level of (for example) 8.
  What would its new level be assuming that
  "Find a second job" was enacted?
* 3
  Consider the following objectives"
   1  Have large assets
   2  Have high steady income
  Does the action strategy "Increase my over-time"
  have any adverse effect on any of the above objectives?
* yes                                                          C-18
  List the affected objectives by number (separated by spaces)
* 1
  Suppose that the objective "Have large assets"
  would otherwise attain a level of (for example) 8.
  What would its new level be assuming that
  "Increase my over-time" was enacted?
* 4
  Let's consider the action strategy "Develop my land"
  List the names for various detailed methods by which
  "Develop my land" can be executed.
  1:
* ?
  Normally, approaches such as "Develop my land" can be
  executed in a variety of different ways (methods)
  in varying degrees of detail.  Think about the most
  promising execution plans available and list
  their names.  (Make sure that the list
  consists of mutually exclusive modes of operation).
  1:
* Build a house                                                C-19
  2:
*
  For each mode, re-estimate the level (0 to 10) that
  "Have large assets" would attain as a result of enacting:
  action mode 1:  "Develop my land - Build a house"
* ?
  You previously estimated that "Develop my land"
  would have a certain effectiveness on a scale from
  0 to 10.  Normally, this value depends on the
  selected mode of implementation.  For each listed
  mode, enter the revised level that objective
  "Have large assets" would assume, given that the mode
  was actually implemented.
  action mode 1:  "Develop my land - Build a house"
* 9
  Let's consider the action strategy "Invest in stock market"
  List the names for various detailed methods by which
  "Invest in stock market" can be executed.
  1:
* Utilities                                                    C-20
  2:
* Energy
  3:
* Electronics
  4:
*
```

```
  For each mode, re-estimate the level (0 to 10) that
  "Have large assets" would attain as a result of enacting:
  action mode 1:  "Invest in stock market - Utilities"
* 5                                                          C-21
  action mode 2:  "Invest in stock market - Energy"
* 7                                                          C-22
  action mode 3:  "Invest in stock market - Electronics"
* 8                                                          C-23
  Let's consider the action strategy "Invest in real estate"
  List the names for various detailed methods by which
  "Invest in real estate" can be executed.
  1:
* Apartment building
  2:
* Undeveloped land
  3:
*
  For each mode, re-estimate the level (0 to 10) that
  "Have large assets" would attain as a result of enacting:
  action mode 1:  "Invest in real estate - Apartment building"
* 7                                                          C-24
  action mode 2:  "Invest in real estate - Undeveloped land"
* 5                                                          C-25
  Let's consider the action strategy "Speculate in precious metals"
  List the names for various detailed methods by which
  "Speculate in precious metals" can be executed.
  1:
* Gold
  2:
* Silver
  3:
*
  For each mode, re-estimate the level (0 to 10) that
  "Have large assets" would attain as a resulting of enacting:
  action mode 1:  "Speculate in precious metals - Gold"
* 7                                                          C-26
  action mode 2:  "Speculate in precious metals - Silver"
* 5                                                          C-27
  Let's consider the action strategy "Open a business"
  List the names for various detailed methods by which
  "Open a business" can be executed.
  1:
* Franchise                                                  C-28
  2:
* Joint venture
  3:
*
  For each mode, re-estimate the level (0 to 10) that
  "Have high steady income" would attain as a result of enacting:
  action mode 1:  "Open a business - Franchise"
* 3                                                          C-29
  action mode 2:  "Open a business - Joint venture"
* 8
```

```
  Let's consider the action strategy "Find a second job"
  List the names for various detailed methods by which
  "Find a second job" can be executed.
  1:
* none                                                          C-30


  Let's consider the action strategy "Increase my over-time"
  List the names for various detailed methods by which
  "Increase my over-time" can be executed.
  1:
* none                                                          C-31


  Let's consider the action mode "Develop my land - Build a house"
  List any preconditions that must be established
  before mode "Develop my land - Build a house" can be implemented.
  1:
* ?                                                             C-32
  Normally, some preparation is usually required to
  secure an effective execution of "Develop my land - Build a house".
  List the conditions that must materialize
  (be satisfied) or must be maintained (required effort
  to guard against deterioration) so that the
  effectiveness of "Develop my land - Build a house" (in terms of accomplishing
  objective "Have large assets") is enhanced or secured.
  1:
* Have sufficient funds
  2:
*
  Let's explore the importance of the realization
  of these preconditions with respect to securing the
  effectiveness of "Develop my land - Build a house".  Estimate
  (on a scale from 0 to 10) the level of completion
  of the preconditions below which "Develop my land - Build a house"
  is totally ineffective.
  precondition 1:  "Have sufficient funds"
* ?                                                             C-33
  It may be helpful to think about two extreme physical
  quantities reflecting the completion level of
  the preconditions to follow.  Mentally assign 10 to
  the highest imagined quantity and 0 to the
  lowest.  Keeping these quantities in mind, estimate
  (on a scale from 0 to 10) where the following
  precondition should be placed so that "Develop my land - Build a house"
  just begins to become effective.
  precondition 1:  "Have sufficient funds"
* 8                                                             C-34
  What level (0 to 10) would you expect the following
  precondition to reach in a well-planned
  strategy aimed at realizing the precondition in question
  and at the same time not having a
  severe adverse effect on your other objectives?
```

```
  precondition 1:  "Have sufficient funds"
* ?
  Recall your previous experiences in this problem area.
  Imagine similar situations in the past and
  Assume that you are given a sufficient amount of
  time to plan your actions judiciously.
  Estimate a reasonable level (0 to 10) of attainment
  for each precondition to follow
  which reflects both environmental constraints and
  your available resources.
  precondition 1:  "Have sufficient funds"
* 9                                                              C-35
  Let's consider the action mode "Invest in stock market - Utilities"
  List any preconditions that must be established
  before mode "Invest in stock market - Utilities" can be implemented.
  1:
* none                                                           C-36


  Let's consider the action mode "Invest in stock market - Energy"
  List any preconditions that must be established
  before mode "Invest in stock market - Energy" can be implemented.
  1:
* none                                                           C-37


  Let's consider the action mode "Invest in stock market - Electronics"
  List any preconditions that must be established
  before mode "Invest in stock market - Electronics" can be implemented.
  1:
* none                                                           C-38


  Let's consider the action mode "Invest in real estate - Apartment building"
  List any preconditions that must be established
  before mode "Invest in real estate - Apartment building" can be implemented.
  1:
* Secure apartment loan
  2:
*
  Let's explore the importance of the realization
  of these preconditions with respect to securing the
  effectiveness of "Invest in real estate - Apartment building".  Estimate
  (on a scale from 0 to 10) the level of completion
  of the preconditions below which "Invest in real estate - Apartment building"
  is totally ineffective.
  precondition 1:  "Secure apartment loan"
* 1                                                              C-39
  What level (0 to 10) would you expect the following
  precondition to reach in a well-planned
  strategy aimed at realizing the precondition in question
  and at the same time not having a
  severe adverse effect on your other objectives?
```

precondition 1: "Secure apartment loan"
* 8 C-40
Let's consider the action mode "Invest in real estate - Undeveloped land"
List any preconditions that must be established
before mode "Invest in real estate - Undeveloped land" can be implemented.
1:
* Secure land loan C-41
2:
*
Let's explore the importance of the realization
of these preconditions with respect to securing the
effectiveness of "Invest in real estate - Undeveloped land". Estimate
(on a scale of 0 to 10) the level of completion
of the preconditions below which "Invest in real estate - Undeveloped land"
is totally ineffective.
precondition 1: "Secure land loan"
* 1 C-42
What level (0 to 10) would you expect the following
precondition to reach in a well-planned
strategy aimed at realizing the precondition in question
and at the same time not having a
severe adverse effect on your other objectives?
precondition 1: "Secure land loan"
* 8
Let's consider the action mode "Speculate in precious metals - Gold"
List any preconditions that must be established
before mode "Speculate in precious metals - Gold" can be implemented.
1:
* none C-43

Let's consider the action mode "Speculate in precious metals - Silver"
List any preconditions that must be established
before mode "Speculate in precious metals - Silver" can be implemented.
1:
* none C-44

Let's consider the action mode "Open a business - Franchise"
List any preconditions that must be established
before mode "Open a business - Franchise" can be implemented.
1:
* none C-45

Let's consider the action mode "Open a business - Joint venture"
List any preconditions that must be established
before mode "Open a business - Joint venture" can be implemented.
1:
* Having management assistance C-46
2:
*

Let's explore the importance of the realization
of these preconditions with respect to securing the
effectiveness of "Open a business - Joint venture". Estimate
(on a scale from 0 to 10) the level of completion
of the preconditions below which "Open a business - Joint venture"
is totally ineffective.
precondition 1: "Having management assistance"
* 2 C-47
What level (0 to 10) would you expect the following
precondition to reach in a well-planned
strategy aimed at realizing the precondition in question
and at the same time not having a
severe adverse effect on your other objectives?
precondition 1: "Having management assistance"
* 6 C-48
Let's consider the precondition "Have sufficient funds"
List conditions over which you have no direct control
but which may, if they hold true,
significantly impair or enhance the degree of
effectiveness of "Develop my land - Build a house".
1:
* ?
Consider the effect of "Develop my land - Build a house" on "Have large assets".
There may be uncertain factors (possible
events, unexpected developments, unknown conditions, etc.)
whose occurrence will significantly
influence the effectiveness of "Develop my land - Build a house".
Name such events.
1:
* Funds available
2:
* Funds not available
3:
*
What is the probability that the following event
will hold true? (e.g. 0.6)
state 1: "Funds available"
* .7 C-49
state 2: "Funds not available"
* .3
Previously, you estimated that enacting "Develop my land - Build a house"
would result in level 9 for objective "Have large assets".
Now, suppose that the following event occurs.
Re-estimate the new level objective
"Have large assets" would reach.
state 1: "Funds available"
* 8
state 2: "Funds not available"
* 2 C-50
Let's consider the precondition "Secure apartment loan"
List conditions over which you have no direct control
but which may, if they hold true,
significantly impair or enhance the degree of
effectiveness of "Invest in real estate - Apartment building".

```
  1:
* Apartment loan approved
  2:
* Apartment loan denied
  3:
*
  What is the probability that the following event
  will hold true? (e.g.  0.6)
  state 1:  "Apartment loan approved"
* .8                                                          C-51
  state 2:  "Apartment loan denied"
* .2
  Previously, you estimated that enacting "Invest in real estate - Apartment
  building" would result in level 6 for objective "Have large assets".
  Now, suppose that the following event occurs.
  Re-estimate the new level objective
  "Have large assets" would reach.
  state 1:  "Apartment loan approved"
* 10                                                          C-52
  state 2:  "Apartment loan denied"
* 0
  Let's consider the precondition "Secure land loan"
  List conditions over which you have no direct control
  but which may, if they hold true,
  significantly impair or enhance the degree of
  effectiveness of "Invest in real estate - Undeveloped land".
  1:
* Land loan approved
  2:
* Land loan denied
  3:
*
  What is the probability that the following event
  will hold true?  (e.g.  0.6)
  state 1:  Land loan approved"
* .6                                                          C-53
  state 2:  Land loan denied"
* .4
  Previously, you estimated that enacting "Invest in real estate - Undeveloped land"
  would result in level 6 for objective "Have large assets".
  Now, suppose that the following event occurs.
  Re-estimate the new level objective
  "Have large assets" would reach.
  state 1:  "Land loan approved"
* 10                                                          C-54
  state 2:  "Land loan denied"
* 0
  Let's consider the precondition "Having management assistance"
  List conditions over which you have no direct control
  but which may, if they hold true,
  significantly impair or enhance the degree of
  effectiveness of "Open a business - Joint venture".
```

```
  1:
* Assistance available
  2:
* Assistance not available
  3:
*
  What is the probability that the following event
  will hold true?  (e.g.  0.6)
  state 1:  "Assistance available"
* .5                                                              C-55
  state 2:  "Assistance not available"
* .5
  Previously, you estimated that enacting "Open a business - Joint venture"
  would result in level 7 for objective "Have high steady income".
  Now, suppose that the following event occurs.
  Re-estimate the new level objective
  "Have high steady income" would reach.
  state 1:  "Assistance available"
* 4                                                               C-56
  state 2:  "Assistance not available"
* 7
  Let's consider the state "Funds available"
  Consider this state as a new goal.
  List all major objectives which, if realized, would
  contribute to the fulfillment of the goal.
  1:
* Get funds
  2:
*
  What level (0 to 10) is the following objective
  expected to reach in a well-planned strategy"
  objective 1:  "Get funds"
* 7                                                               C-57
  Let's consider the state "Apartment loan approved"
  Consider this state as a new goal.
  List all major objectives which, if realized, would
  contribute to the fulfillment of the goal.
  1:
* none                                                            C-58


  Let's consider the state "Land loan approved"
  Consider this state as a new goal.
  List all major objectives which, if realized, would
  contribute to the fulfillment of the goal.
  1:
* none


  Let's consider the state "Assistance available"
  Consider this state as a new goal.
  List all major objectives which, if realized, would
  contribute to the fulfillment of the goal.
```

```
  1:
* Find management assistance                                        C-59
  2:
*
  What level (0 to 10) is the following objective
  expected to reach in a well-planned strategy?
  objective 1:  "Find management assistance"
* 7                                                                 C-60
  Let's consider the objective "Get funds"
  List all possible action strategies that you can take
  toward the fulfillment of "Get funds".
  Make sure that the list contains all
  physically feasible approaches (including possibly
  "doing nothing") and that no two of them can be combined.
  1:
* Get building loan                                                 C-61
  2:
* Refinance my house
  3:
* Join with another investor
  4:
*
  Suppose that these actions are taken.  What is your
  assessment of the resulting level of attainment
  of "Get funds" under such conditions?
  action strategy 1:  "Get building loan"
* 8                                                                 C-62
  action strategy 2:  "Refinance my house"
* 7
  action strategy 3:  "Join with another investor"
* 8
  Consider the following objectives:
   1  Have large assets
   2  Have high steady income
   3  Get funds
   4  Find management assistance
  Does the action strategy "Get building loan"
  have any adverse effect on any of the above objectives"
* yes                                                               C-63
  List the affected objectives by number (separated by spaces)
* 2
  Suppose that the objective "Have high steady income"
  would otherwise attain a level of (for example) 8.
  What would its new level be assuming that
  "Get building loan" was enacted?
* 6                                                                 C-64
  Consider the following objectives:
   1  Have large assets
   2  Have high steady income
   3  Get funds
   4  Find management assistance
```

```
  Does the action strategy "Refinance my house"
  have any adverse effect on any of the above objectives?
* yes                                                          C-65
  List the affected objectives by number (separated by spaces)
* 2
  Suppose that the objective "Have high steady income"
  would otherwise attain a level of (for example) 8.
  What would its new level be assuming that
  "Refinance my house" was enacted?
* 6
  Consider the following objectives:
   1  Have large assets
   2  Have high steady income
   3  Get funds
   4  Find management assistance
  Does the action strategy "Join with another investor"
  have any adverse effect on any of the above objectives?
* no                                                           C-66
  Let's consider the objective "Find management assistance"
  List all possible action strategies that you can take
  toward the fulfillment of "Find management assistance".
  Make sure that the list contains all
  physically feasible approaches (including possibly
  "doing nothing") and that no two of them can be combined.
  1:
* Get a partner
  2:
* Hire a manager                                               C-67
  3:
* Join an existing business
  4:
*
  Suppose that these actions are taken.  What is your
  assessment of the resulting level of attainment
  of "Find management assistance" under such conditions?
  action strategy 1:  "Get a partner"
* 8                                                            C-68
  action strategy 2:  "Hire a manager"
* 7
  action strategy 3:  "Join an existing business"
* 9
  Consider the following objectives:
   1  Have large assets
   2  Have high steady income
   3  Get funds
   4  Find management assistance
  Does the action strategy "Get a partner"
  have any adverse effect on any of the above objectives?
* no
  Consider the following objectives:
   1  Have large assets
   2  Have high steady income
   3  Get funds
   4  Find management assistance
```

```
  Does the action strategy "Hire a manager"
  have any adverse effect on any of the above objectives?
* no
  Consider the following objectives:
   1  Have large assets
   2  Have high steady income
   3  Get funds
   4  Find management assistance
  Does the action strategy "Join an existing business"
  have any adverse effect on any of the above objectives?
* yes                                                          C-69
  List the affected objectives by number (separated by spaces)
* 1
  Suppose that the objective "Have large assets"
  would otherwise attain a level of (for example) 8.
  What would its new level be assuming that
  "Join an existing business" was enacted?
* 6
  Let's consider the action strategy "Get building loan"
  List the names for various detailed methods by which
  "Get building loan" can be executed.
  terminate
  Exit elicitation mode.
  Enter system mode.
```

Resulting Graph Structure

```
      structure
(Node number, Node name, Value, Modifier.)
Improve my financial status  0
     objective (level 1)
-    1. Have large assets  6  6
          action strategy (level 2)
-    -    1. Develop my land  9  0
               action mode (level 3)
-    -    -    1. Develop my land - Build a house  9  0
                    precondition (level 4)
-    -    -    -    1. Have sufficient funds  9  8
                         state (level 5)
-    -    -    -    -    1. Funds available  8  0.7
                              objective (level 1)
-    -    -    -    -    -    3. Get funds  7  10
                                   action strategy (level 2)
-    -    -    -    -    -    -    8. Get building loan  8  0
-    -    -    -    -    -    -    9. Refinance my house  7  0
-    -    -    -    -    -    -    10. Join with another investor  8  0
-    -    -    -    -    2. Funds not available  2  0.3
-    -    2. Invest in stock market  6  0
               action mode (level 3)
-    -    -    2. Invest in stock market - Utilities  5  0
-    -    -    3. Invest in stock market - Energy  7  0
-    -    -    4. Invest in stock market - Electronics  8  0
-    -    3. Invest in real estate  7  0
               action mode (level 3)
-    -    -    5. Invest in real estate - Apartment building  7  0
                    precondition (level 4)
-    -    -    -    2. Secure apartment loan  8  1
                         state (level 5)
-    -    -    -    -    3. Apartment loan approved  10  0.8
-    -    -    -    -    4. Apartment loan denied  0  0.2
-    -    -    6. Invest in real estate - Undeveloped land  5  0
                    precondition (level 4)
-    -    -    -    3. Secure land loan  8  1
                         state (level 5)
-    -    -    -    -    5. Land loan approved  10  0.6
-    -    -    -    -    6. Land loan denied  0  0.4
-    -    4. Speculate in precious metals  6  0
               action mode (level 3)
-    -    -    7. Speculate in precious metals - Gold  7  0
-    -    -    8. Speculate in precious metals - Silver  5  0
```

```
-    2. Have high steady income  7  4
          action strategy (level 2)
-    -    5. Open a business  8  0
               action mode (level 3)
-    -    -    9. Open a business - Franchise  3  0
-    -    -    10. Open a business - Joint venture  8  0
                    precondition (level 4)
-    -    -    -    4. Having management assistance  6  2
                         state (level 5)
-    -    -    -    -    7. Assistance available  4  0.5
                              objective (level 1)
-    -    -    -    -    -    4. Find management assistance  7  10
                                   action strategy (level 2)
-    -    -    -    -    -    -    11. Get a partner  8  0
-    -    -    -    -    -    -    12. Hire a manager  7  0
-    -    -    -    -    -    -    13. Join an existing business  9  0
-    -    -    -    -    8. Assistance not available  7  0.5
-    -    6. Find a second job  4  0
-    -    7. Increase my over-time  4  0
Side effects:
(Action number, Affected objective number, Adverse effect)
1  2  0.625
4  2  0.75
5  1  0.375
6  1  0.375
7  1  0.5
8  2  0.75
9  2  0.75
13  1  0.75
```

Figure 5 represents a graphical layout of this structure.

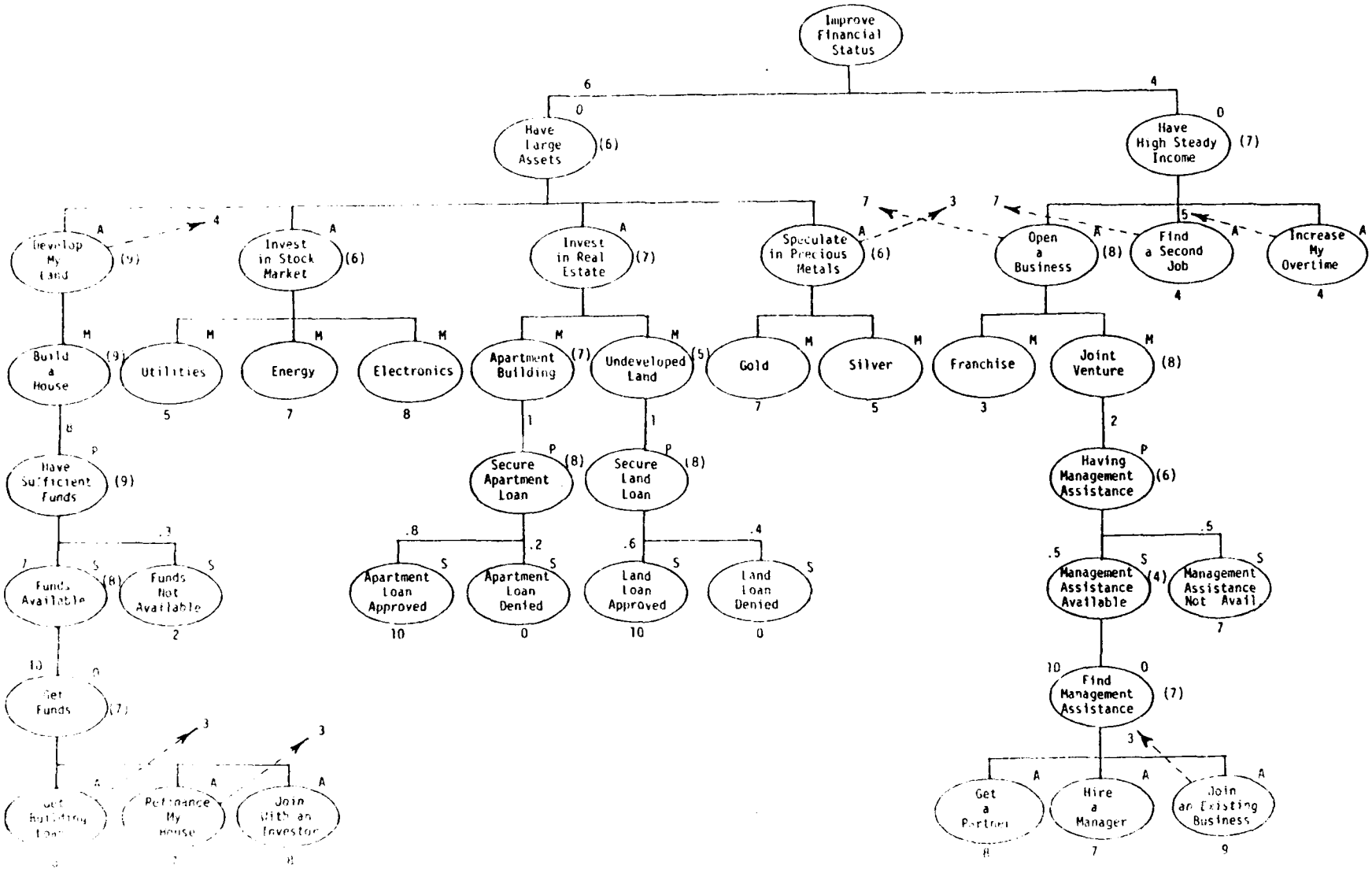


Figure 5. Graphical Representation of Problem Structure Elicited from the Dialogue

System Recommendation

The goal of "Improve my financial status" can be attained to level of 4.55 if the following actions are taken:

Implement "Invest in stock market - Electronics" toward the objective "Have large assets".

Simultaneously, implement "Get a partner" toward "Find management assistance" which will eventually facilitate implementation of "Open a business - Joint venture" leading to attainment of "Have high steady income".

7. EVALUATION AND FUTURE PROSPECTS

A brief examination of the dialogue presented in the last chapter reveals the main strengths and weaknesses of this support system. The most striking negative features of this dialogue are its apparent length and repetitiveness. These weaknesses can be attributed to several factors; some are basic to all fully-computerized situation-based support systems and others are due to the incomplete state of the current version of the program.

The repetitive, mechanical style displayed by the present form of the program is partly due to the fact that in this phase of the research, we have made no special effort to equip the program's queries with a more natural 'flair'. A significantly more human style of conversation can, for example, be obtained by a random selection of synonymous phrases to avoid repetition (see Leal and Pearl, 1977) and by exposing the queries' purpose, e.g., "It is crucial that we first examine ways of achieving 'X'" or "I am trying to find out whether you foresee any special difficulties in executing 'Y'", etc. Simple language-analysis features such as syntactic transformations, word matching, and key-word control would also greatly enhance the natural flavor of the dialogue style.

A more drastic leap toward natural discourse can, of course, be achieved by equipping GODDESS with some rudimentary knowledge about the domain of discourse. For example, a simple semantic network for basic real-estate relationships could assist GODDESS in producing the phrase, 'Lets consider the option of investing in real-estate by purchasing an apartment building', instead of the awkward concatenation, 'Invest in real estate - apartment building' used by GODDESS. However, our primary commitment in this project has been to construct and explore a totally domain-independent system. We believe that the weakness of GODDESS' style of discourse is a small price to pay for the benefit

of using a single program to assist any advice seeker, from a real-estate investor to the President of the United States.

Several observers of GODDESS have also commented that they sometimes feel uncomfortable assigning numerical values to the judgments requested, and that they occasionally feel unsure of what these numerical values represent or how to calculate them. The current system is equipped with several instructional features which can provide, upon request, a more detailed explanation of the nature of the assessment requested. Part of the 'assessment discomfort' can be alleviated by improving these features, and part would be remedied when the dialogue-management program is installed and the user is asked to provide not a single number but a range of possible values.

However, we attribute the basic difficulty connected with assessing levels of attainment and strengths of influences to the fact that in everyday discourse, these same concepts and relations are communicated in qualitative, non-numeric castings. Not too long ago, before the general public became accustomed to numerical broadcasting of weather-predictions and accident statistics, the quantification of likelihood judgments (i.e., probability) met with similar resistance and uneasiness. We also found that after several days of working with the system, users saw no difficulty in interpreting and performing the assessments required. Consequently, we hope that the decision makers who could benefit from frequent consultation with such support systems will quickly become familiar with its somewhat non-traditional parameters.

For the occasional, inexperienced, and non-technical users, we are currently examining a more drastic, but more promising, solution: <u>disposing with numerical estimates altogether</u>. Most of human knowledge and skills are acquired via non-numerical media. Most training manuals and committee's reports convey useful information in purely linguistic terms. We read a newspaper article and

feel very comfortable with statements such as "This vote by Congress would substantially impair the President's bargaining power." Although phrased qualitatively, we do acknowledge that such a statement conveys important and useful factual information without insisting on numerical explication of the degree of impairment. Similarly, it would be more natural and comfortable for the common decision maker to respond to queries such as:

Computer: "Is this condition absolutely necessary for action A or just desirable?"

or

Computer: "Is it very likely or just probable? Choose the most appropriate term:

remotely possible, possible, probable, quite probable, likely, very likely, almost sure, ...

Behind the scenes, the program can map the user's linguistic response onto an appropriate numerical scale and propagate the resulting value through the graph by the methods described in Section 4. The user, however, will be spared the labor of quantifying inherently linguistic variables and the guilt associated with issuing uncertain estimates.

This approach will undoubtedly raise objections of the traditional analysts who may view the reliance on linguistic, rather than numerical, inputs as a backward regress toward the prescientific era of speculative alchemy and 'seat of the pants' decision making. However, the ultimate objective of decision analysis is to provide both formal and valid representations of the decision maker's experience. Forcing a person to produce numbers would not, by itself, make the representation more valid, especially when one's experience is encoded qualitatively. A more reasonable approach would be to incorporate into the

formal model as many of these qualitative relations as possible, so as to make the end results insensitive to the exact magnitude assigned to each relation. We believe the goal-directed structure is a step in this direction; it is made up of many detailed and cognitively clear relationships which render the exact quantification of each component less critical. We feel, for instance, that the statement, "Noise level and safety are two factors of 'roughly equal' importance," conveys more reliable information than any reasonable numerical response to the query: "How many people seriously injured or killed per year, call that number x, makes you indifferent between the option: [x injured or killed and 2500 persons subjected to high noise levels] and the option: [one person injured or killed and 1,500,000 subjected to high noise levels]?" (Slovic et al., 1977, quotation from Keeney's analysis of 'The Mexico City Airport').

Succinctly, our basic position on this issue can be summarized by the belief that qualitative relationships of many cognitively meaningful concepts can be made to produce more accurate results than numerical quantification of few cognitively unmanageable relationships.

Although we have not performed systematic experiments for evaluating the merit of GODDESS (such experiments are currently under way), it appears that the goal-directed structure offers several advantages over the traditional decision tree approach. Our personal experiences with the two types of decision support systems confirm earlier expectations that the goal-directed approach would offer superiority in both clarity and purposefulness.

We find it clear, natural, and pleasing to talk about one's need to obtain a loan in order to build a house, to quantify the degree of this need, or to express directly the fact that refinancing one's house would diminish one's spendable income. These options of expression are simply not provided by the decision tree approach, where only action-sequences and world-states are

considered, while conditions, issues, and factors remain tacit.

Similarly, we have on several occasions noticed that the explicit mention of an objective by the program focuses the attention of the user on a host of related experiences and evokes a number of unconventional alternatives capable of realizing that objective. For example, the idea of refinancing one's house and using the funds to develop one's land is very common to anyone with a little experience in real estate. However, to a user with no previous exposure to real estate manuevers, this possibility either may not occur or, in the more common case, the prospects of entering into debts may be discarded from conscious attention by virtue of emotional barriers or unpleasant associations it may carry. The goal-directed method weakens the impact of such barriers by focusing on a single objective at any given time and instructing the user to ignore, for the moment, all side effects. It should be very hard for the user responding to the query: 'List all possible action strategies that you can take toward the fulfillment of 'Get funds'' not to mention the possibility 'Refinance my house', regardless of the adverse implications that such an alternative may carry.

Recent experiments by Pitz, Sachs, and Heerboth (1980) confirm our belief in the potential of GODDESS to encourage the discovery of novel alternatives. Of several candidate procedures tested for evoking a wider variety of choices, the one based on subgoal elicitation was found to be most effective.

Based on these preliminary results and observations, we cannot rule out the prospect that the goal-directed structure described in this report will develop into the standard architecture for next generation decision-support systems. It offers the capability of continuously sweeping the spectrum between situation-based and knowledge-based systems (depending on the scope and level of details required). It is capable of operating as a fully computerized system

as well as in an 'analyst's apprentice' capacity. Finally, it is conceptually appealing and permits both systematic and directional acquisition of knowledge.

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APPENDIX 1. User Comments During Dialogue

C-1: I did not understand what is meant by importance.

C-2: Although both objectives, 'Have large assets' and 'Have high steady income', are instrumental for improving my financial status, I perceive having large assets to be more crucial to providing improvement in my financial status.

C-3: Considering my present status and potential, it is possible to plan an investment program that would result in assets of about $70k in three years.

C-4: Considering my upcoming promotion and the possibility of increasing my overtime, there is a very high probability of increasing my steady income by about 25 percent in the near future. Besides, there is a possibility of finding a second job, therefore increasing my income by another factor of about 30 percent at the expense of reducing some of my overtime work at the present job.

C-5: Current expected profit margin in land development is extremely high.

C-6: Although I am familiar with some stocks with good expectation, the present economical situation makes investment in the stock market somewhat risky.

C-7: Although the expected recession may decrease the market demand, real estate prices are tied to the inflation rate which is still rising. However, the option of investing in real estate will not be as profitable as developing my land.

C-8: Since I consider buying only futures on a margin, although the price of precious metals rise with inflation, local fluctuations may get me out of the game, thus, loosing even my original investment.

C-9: My present work environment is organized such that compensation, bonuses, and promotions are directly related to my effort. Considering that developing my land will make demands on my time and effort, it may

actually decrease my potential for increasing my steady income.

C-10: Since my investment in the stock market would be through my broker, the required time and effort would be negligible, permitting me to pursue other activities.

C-11: The situation would be the same as investing in the stock market.

C-12: Although speculation in precious metals would also be done through a broker, it requires continuous monitoring and analysis of market behavior, and thus demanding a considerable portion of my time and effort (however, less than the amount required for developing my land).

C-13: Considering my potential level of investment in a business and my degree of capability in running it, I am pretty confident that I can develop a business with a net profit of at least $25k per year.

C-14: I expect finding a second job will increase my steady income by about $17k per year.

C-15: The amount of increase in my overtime at my present job is limited. I expect to be able to increase my income by about $10k per year through extra overtime at my present job.

C-16: Opening a business will occupy so much of my time that I will hardly be able to pursue any active investment at all.

C-17: Having two jobs at the same time takes almost all my time.

C-18: Although not as much as opening a business or having a second job, increasing my overtime sufficiently also decreases my available time and energy for pursuing an active investment.

C-19: Considering the R1 zoning of my land, the only feasible development would be to build a single family residential unit.

C-20: Considering the economic situation and its effect on different stocks, I consider the only three stocks with a promising future to be utilities,

energy, and electronic stocks.

C-21: Although the profit margins of utility companies are increasing, the rise in fuel cost is very likely to slow down the profit margin rate of increase, thus negatively affecting the rate of increase in stocks.

C-22: Energy stocks, especially the alternative energy stocks, are very promising in this period of energy shortage.

C-23: Due to the rapid growth of the industry, resulting from the innovative technology, electronic stocks are probably the most promising stock today.

C-24: Due to the high inflation rate, the price of building materials and construction workers' salaries is rising so rapidly that the rate of increase in the price of the building itself seems to be higher than the rate of increase in the price of undeveloped land.

C-25: Although high inflation is always an insurance for an increase in real estate prices, the potential forthcoming recession will slow down the building activities, thus decreasing the demand for undeveloped land, which in turn will lower the rate of increase in undeveloped land price.

C-26: Due to the historical importance of gold, a high inflation rate will cause the price of gold to increase greatly.

C-27: Although the price of silver also rises according to the inflation rate, since the major use of silver is its industrial application, the potential forthcoming recession will have a negative effect on rising silver prices.

C-28: Since I do not have sufficient know-how in running a business independently. Opening an independent business is not feasible.

C-29: Although major help is offered in areas such as management and advertising by the parent company, a considerable portion of the profit will be indirectly transferred to the parent company.

C-30: There are no different ways of finding a second job.

C-31: There is no other way of increasing my overtime.

C-32: What is meant by precondition?

C-33: I need more explanation.

C-34: Having sufficient funds is very critical. I cannot complete building the house unless initially I have at least 80 percent of the sufficient funds required to build the house.

C-35: Considering available resources, I am very confident that I can acquire the sufficient funds.

C-36: Although there are different utility companies that I can invest in, the nature of the investment in all these prospects would be the same.

C-37: The same as in utility stocks.

C-38: The same as in utility stocks.

C-39: I cannot invest in an apartment building unless I acquire a mortgage loan.

C-40: Considering my credit record, I am pretty confident that I can acquire a mortgage loan.

C-41: The same as in the case of investing in an apartment building.

C-42: Again, acquiring a mortgage loan is absolutely critical.

C-43: The only feasible way to speculate in gold is to buy different gold futures on margin, which are basically the same.

C-44: The same as speculating in gold.

C-45: The nature of all feasible franchises are sufficiently similar.

C-46: Not having sufficient background in managing a business, I need to have some management assistance.

C-47: If I have 50 percent assistance in management, I can still operate a joint venture effectively.

C-48: I think I can find management assistance at least sufficient to effectively run the business.

C-49: Since I have different sources, other than getting a construction loan, to provide funds (such as a second mortgage on my present house), the probability of having funds available is pretty high.

C-50: Even if sufficient funds for completing the building project were not available, I can still increase the value of my land by grading it using some savings that I already have.

C-51: Considering my credit history and the fact that the apartment will create some further income, I will have a good chance of getting my loan approved.

C-52: I can purchase the apartment only if my loan is approved.

C-53: Since the land does not provide any form of income, the chance of approval of a mortgage loan application for purchasing land is less than that for purchasing an apartment.

C-54: Again, I cannot purchase the land unless my loan is approved.

C-55: At this point, I believe that I have a 50-50 chance of finding assistance.

C-56: Without assistance, I can still run the business, but considerably less effectively.

C-57: There is a good chance of getting sufficient funds.

C-58: There is none.

C-59: If there was no assistance available, I can search for other sources (such as finding a partner or employing a manager) for management assistance.

C-60: I have a good chance of finding management assistance for the kind of business I have in mind.

C-61: Besides getting a construction loan or refinancing my present house, I realize that I can provide sufficient funds by joining another investor.

C-62: I believe the capital gain on my house is sufficient. However, I am more confident in the other two alternative ways of acquiring funds.

C-63: Since I have to repay the mortgage loan monthly, my net steady income will decrease.

C-64: Considering the monthly payments and my present income.

C-65: The same as in getting a construction loan.

C-66: Since I offer the land and he provides the money for construction, there will not be any monthly payments from one to the other.

C-67: Now I realize that besides getting a partner or hiring a manager, I can acquire management assistance also by joining an existing business rather than opening my own.

C-68: A partner may also not be a good manager and hired assistance may be good in management but unfamiliar with this business. The partners in an existing business, however, have proven to be good managers and also familiar with the business.

C-69: Although it has many advantages, joining an existing business does not provide me with as much capital investment as in the case of opening my own business. In other words, I am paying something for the convenience of having the management assistance and working business.

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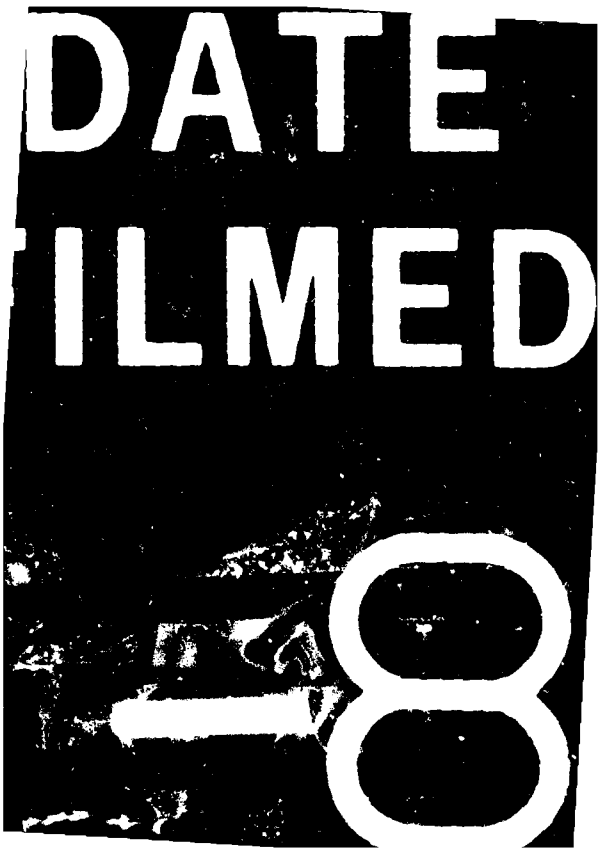
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